The origin of space weather

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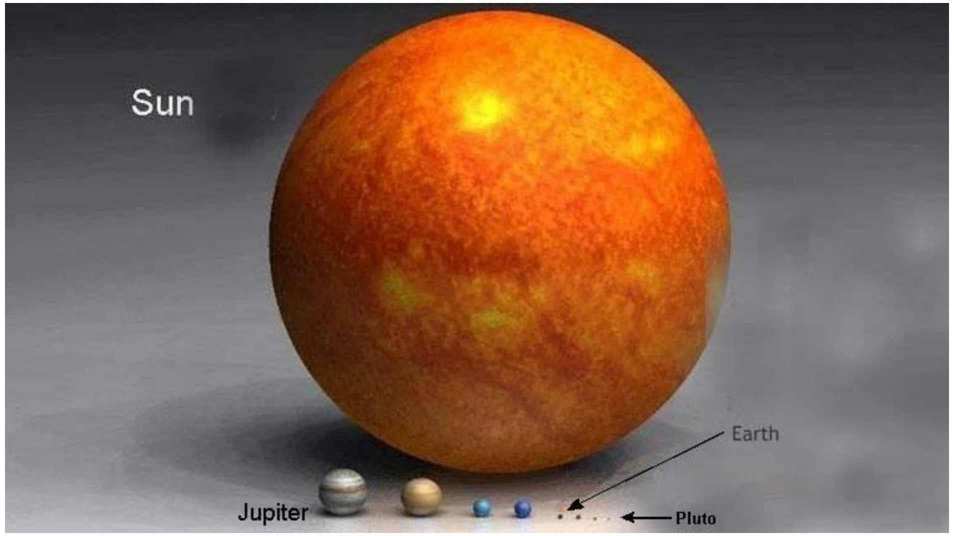
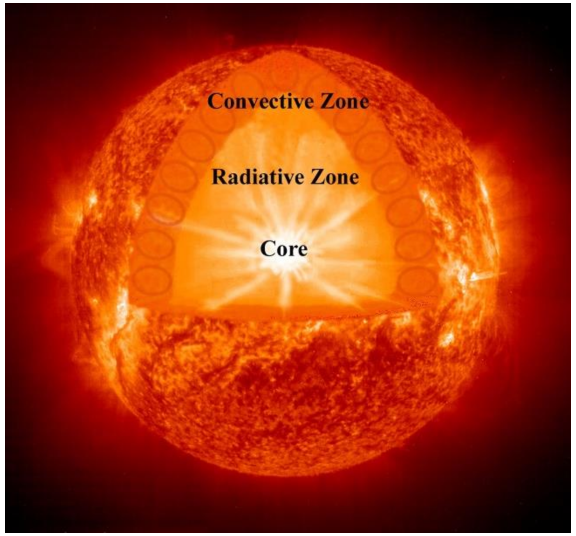
The Sun

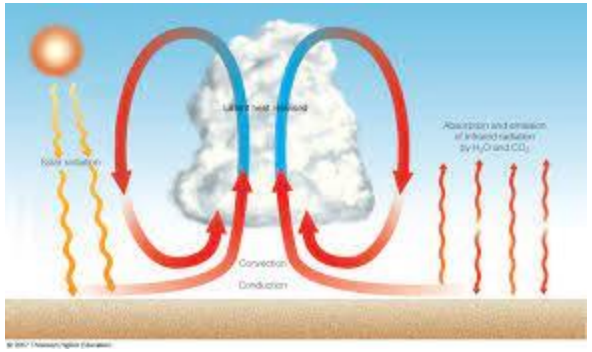




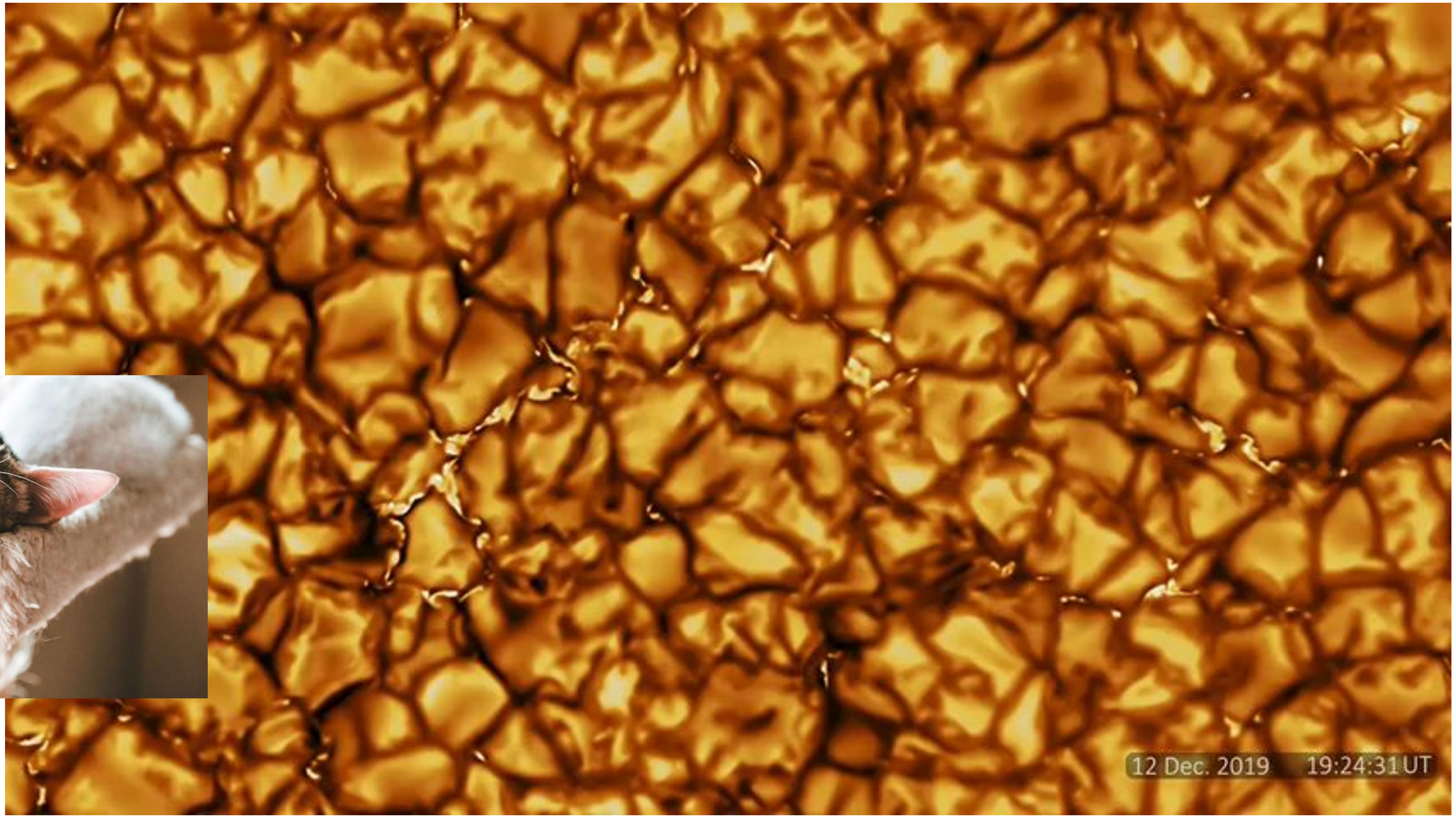
An ordinary star at the center of the solar system.

Gravity at the core is so strong that nuclear fusion turns hydrogen into helium. This energy works its way to the surface over thousands of years.

In the outer 1/3, energy is transported by convective overturning. This motion of ionized gas creates a magnetic field.

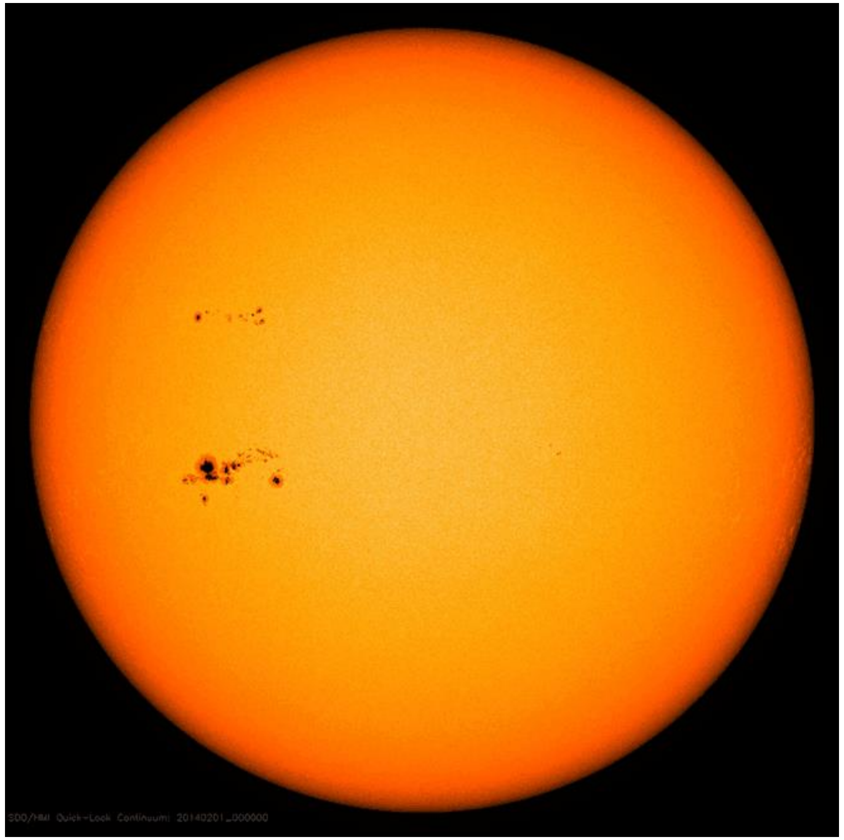


Close up of the surface: constant motion



Cat not to scale.

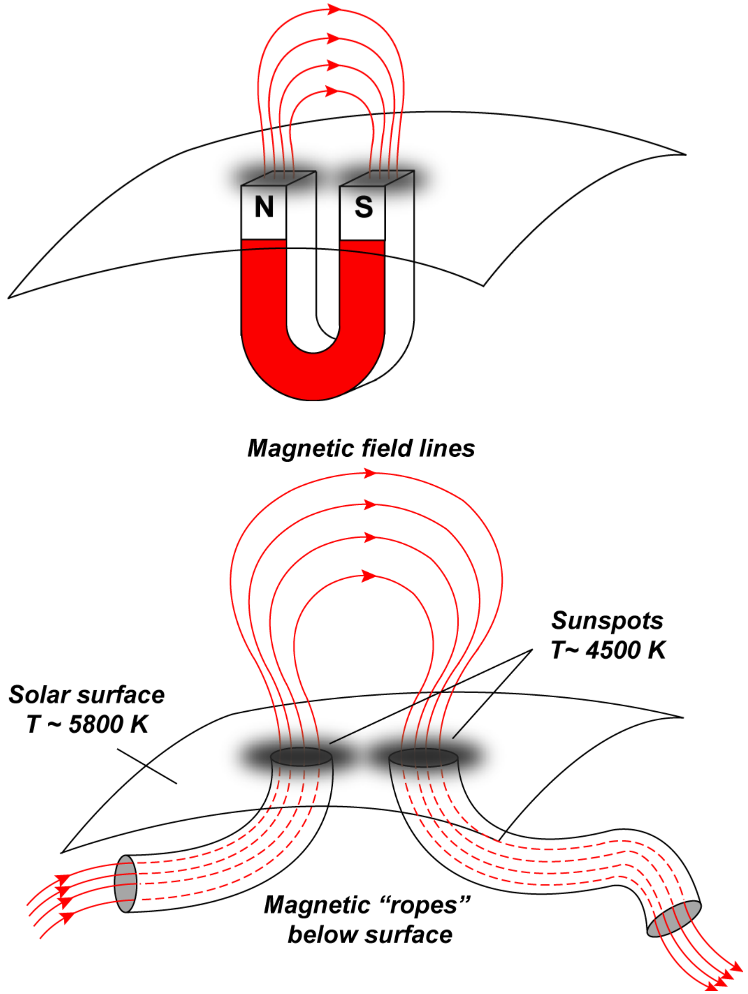
Sun in visible light



The Sun rotates with a period of about 27 days.

Unlike the Earth, there are no permanent features on the Sun. There are magnetic structures that emerge and last for a few months, then dissipate.

The formation of sunspots



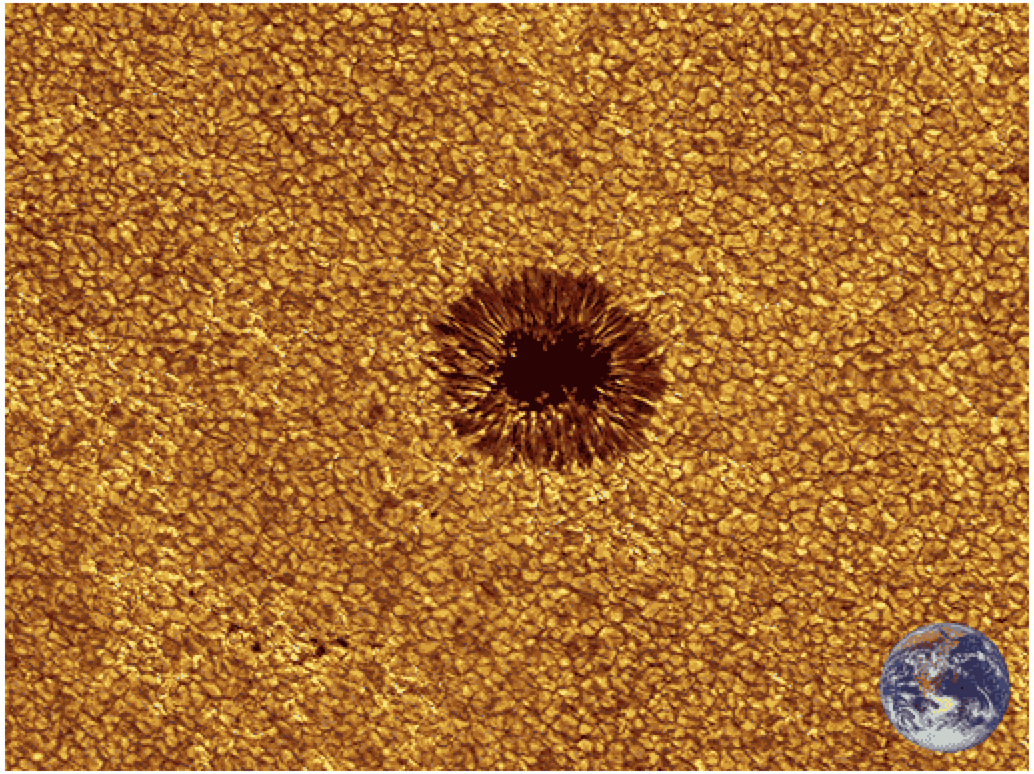
Sunspot

A sunspot is part of a larger structure known as an Active Region.

Sunspots are dark, but only last about one rotation.

The bright region surrounding a sunspot is known as "facula" and can last for several rotations.

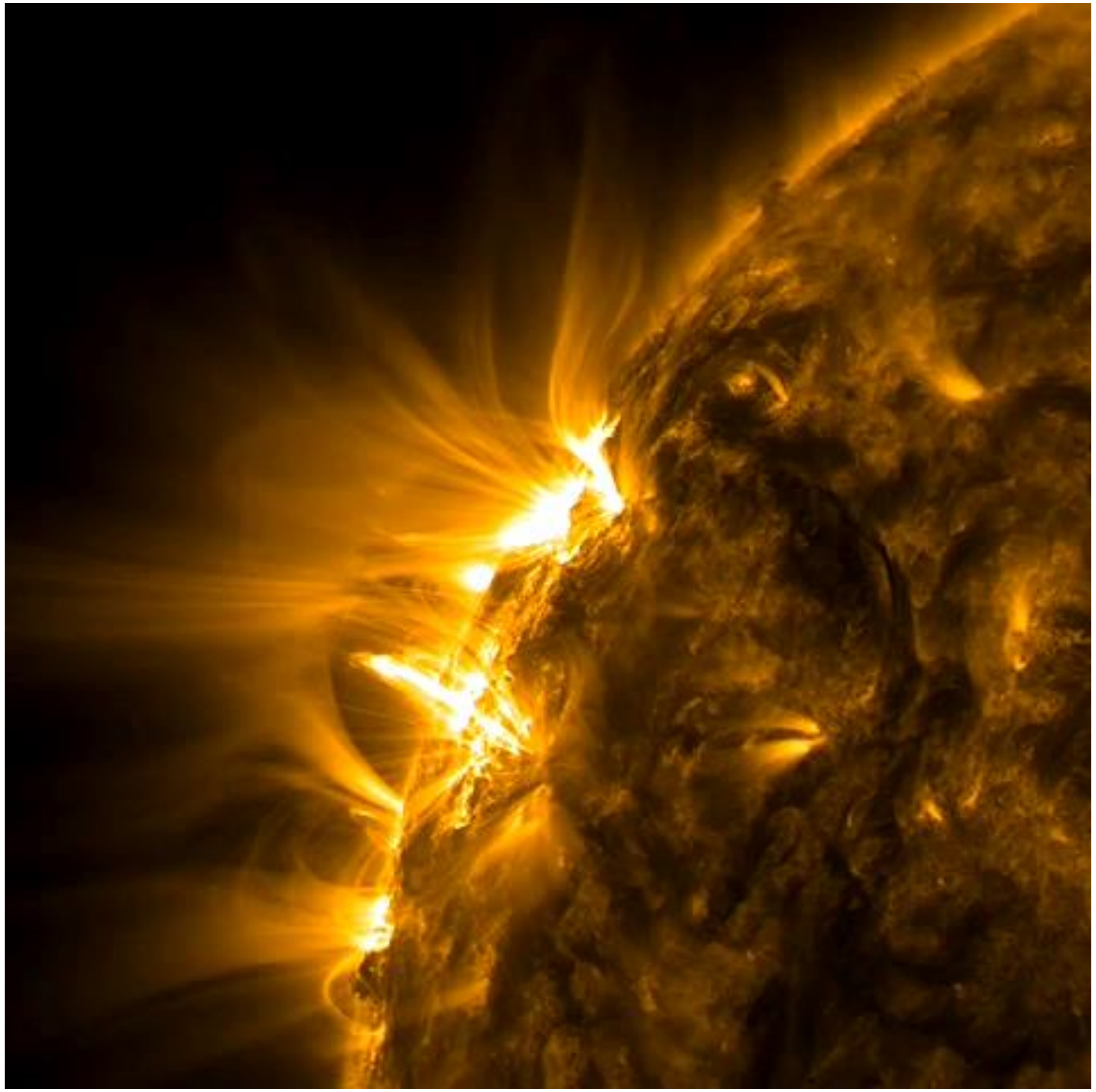
The interplay between bright faculae and dark sunspots causes variations in solar irradiance.



Sunspots usually come in pairs, connected by magnetic field.

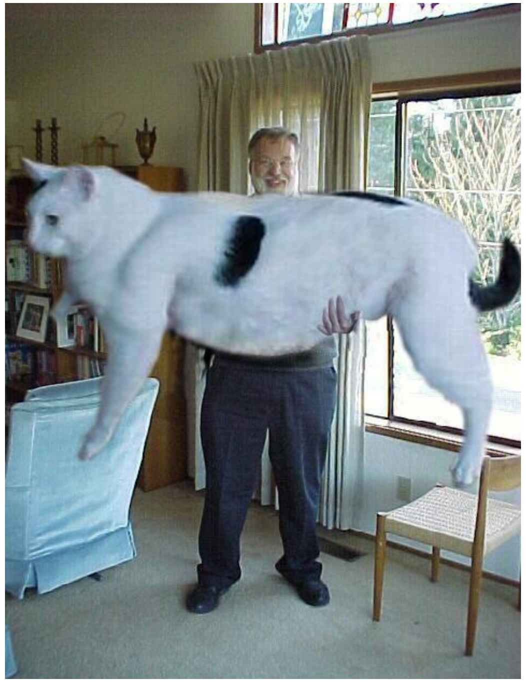
Charged particles (plasma) stay trapped in the magnetic field.

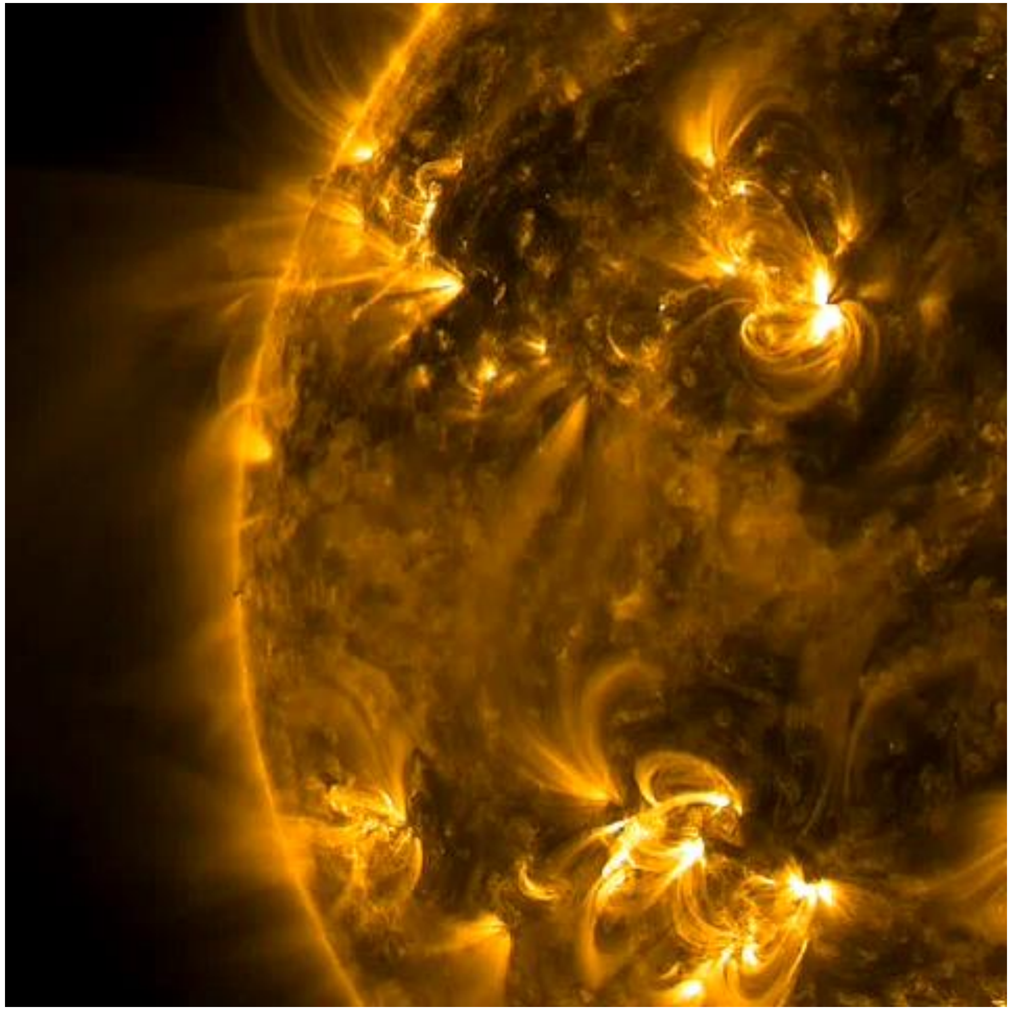
The plasma illuminates the magnetic structures.

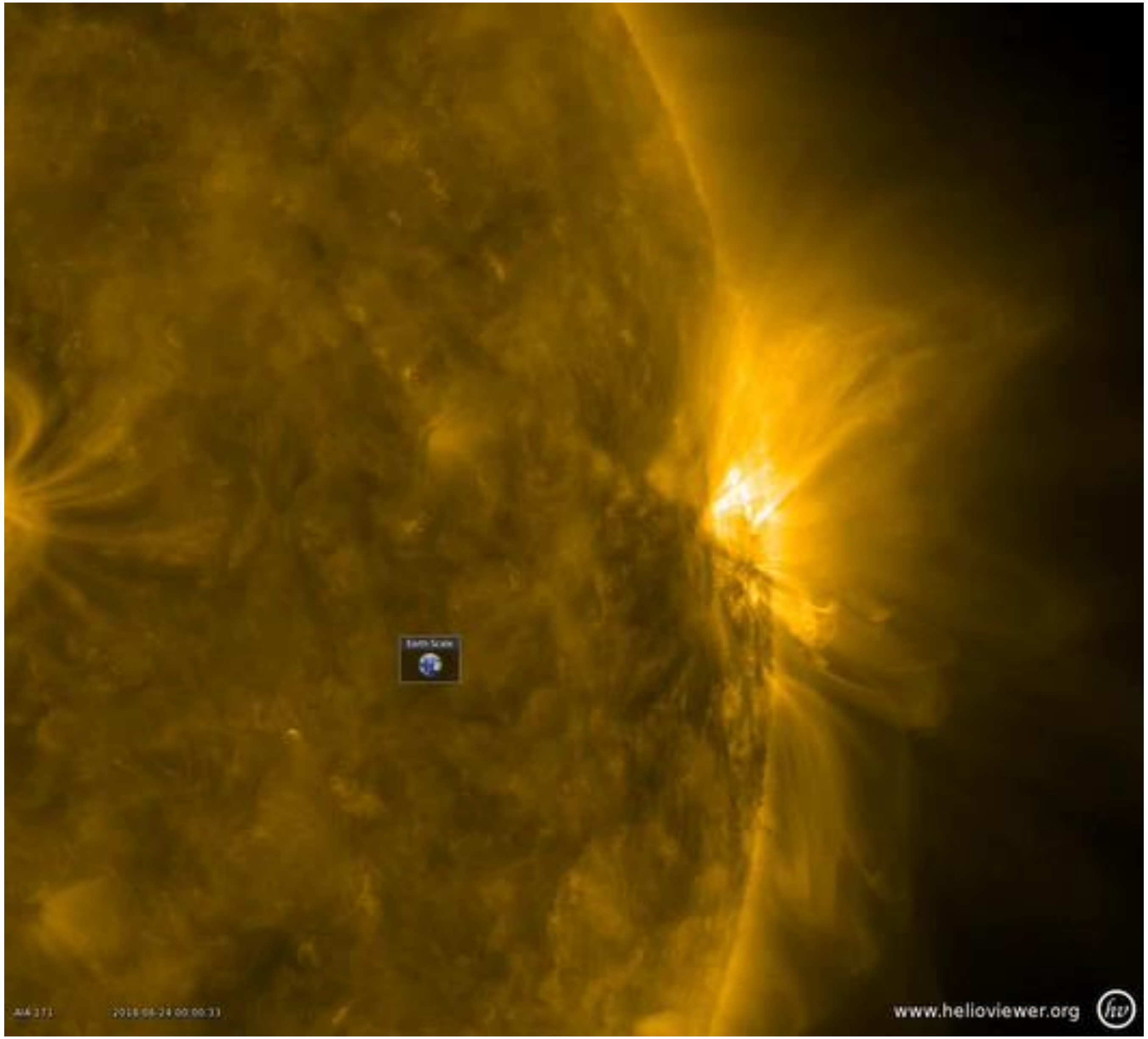


Connection between active regions can extend very far.

Remember how large the Sun is compared to the Earth!





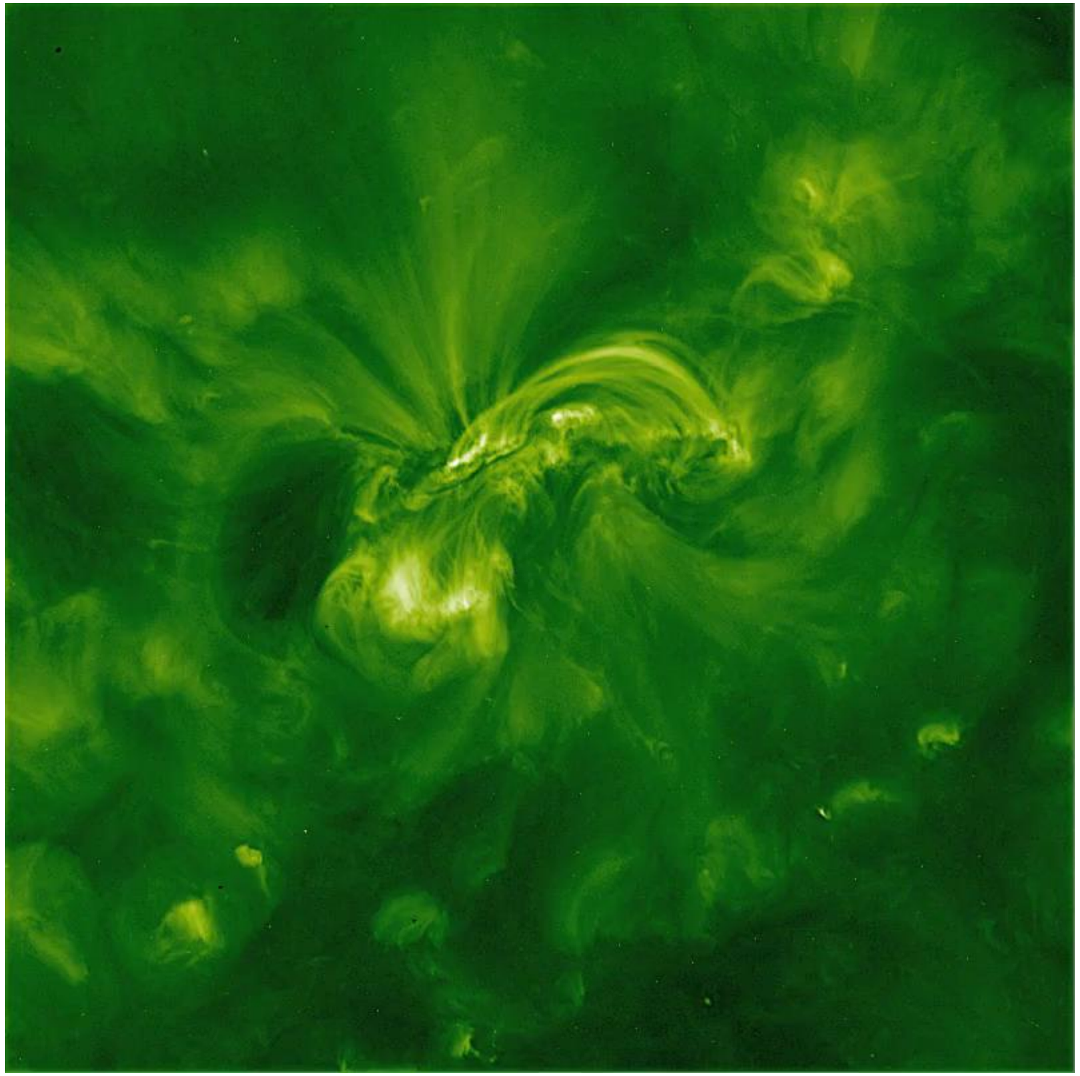


Earth to scale

Motion on the surface can twist the magnetic field like a spring.

The magnetic field can reconnect to a simpler geometry, which can release enormous amounts of energy.

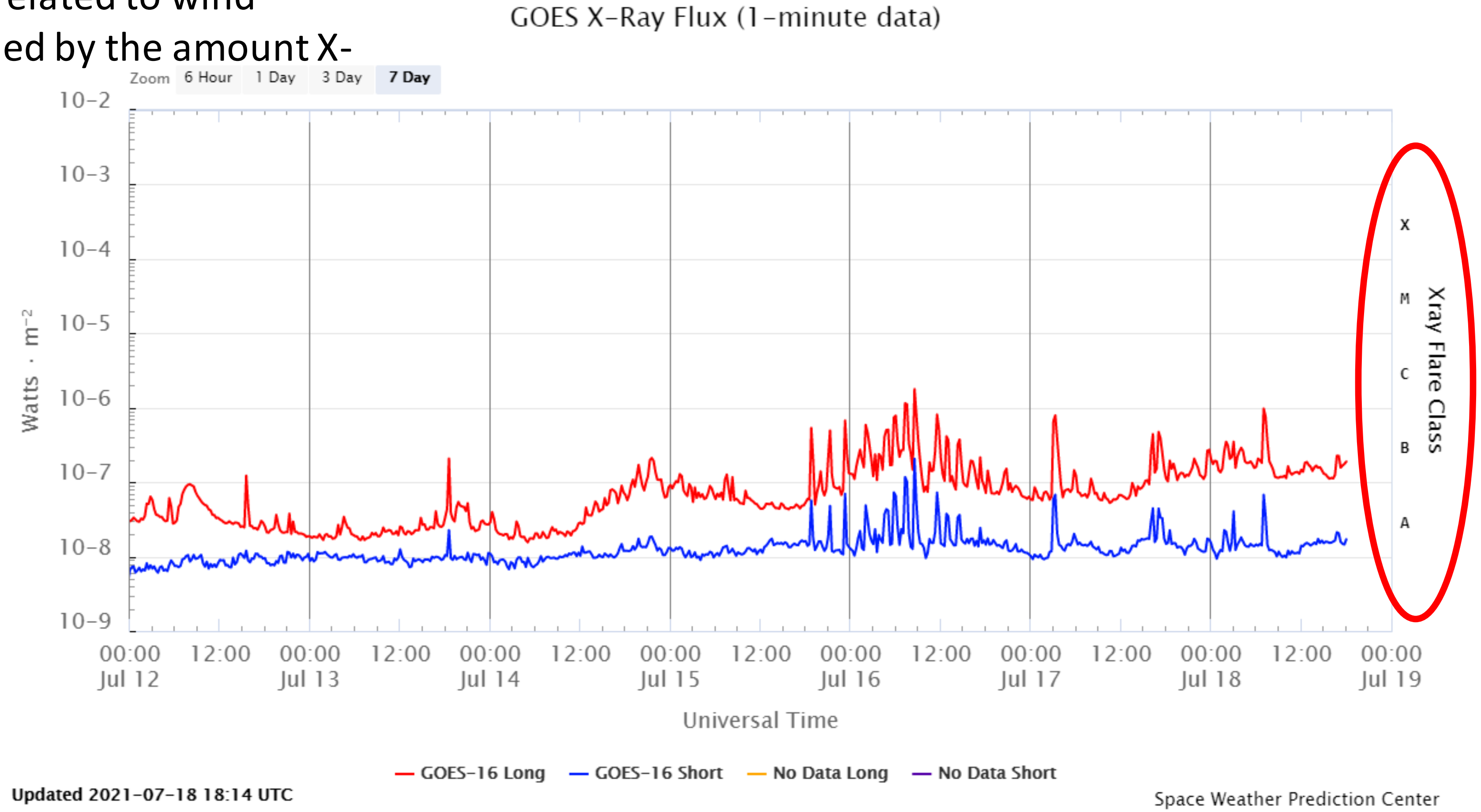
These events are known as flares.



Sizes of flares:

Much like storms on Earth, flares are classified according to strength. A hurricane's strength is related to wind speed. A solar flare's strength is defined by the amount X-rays it emits.

X – extreme
M – medium
A, B, C – all small



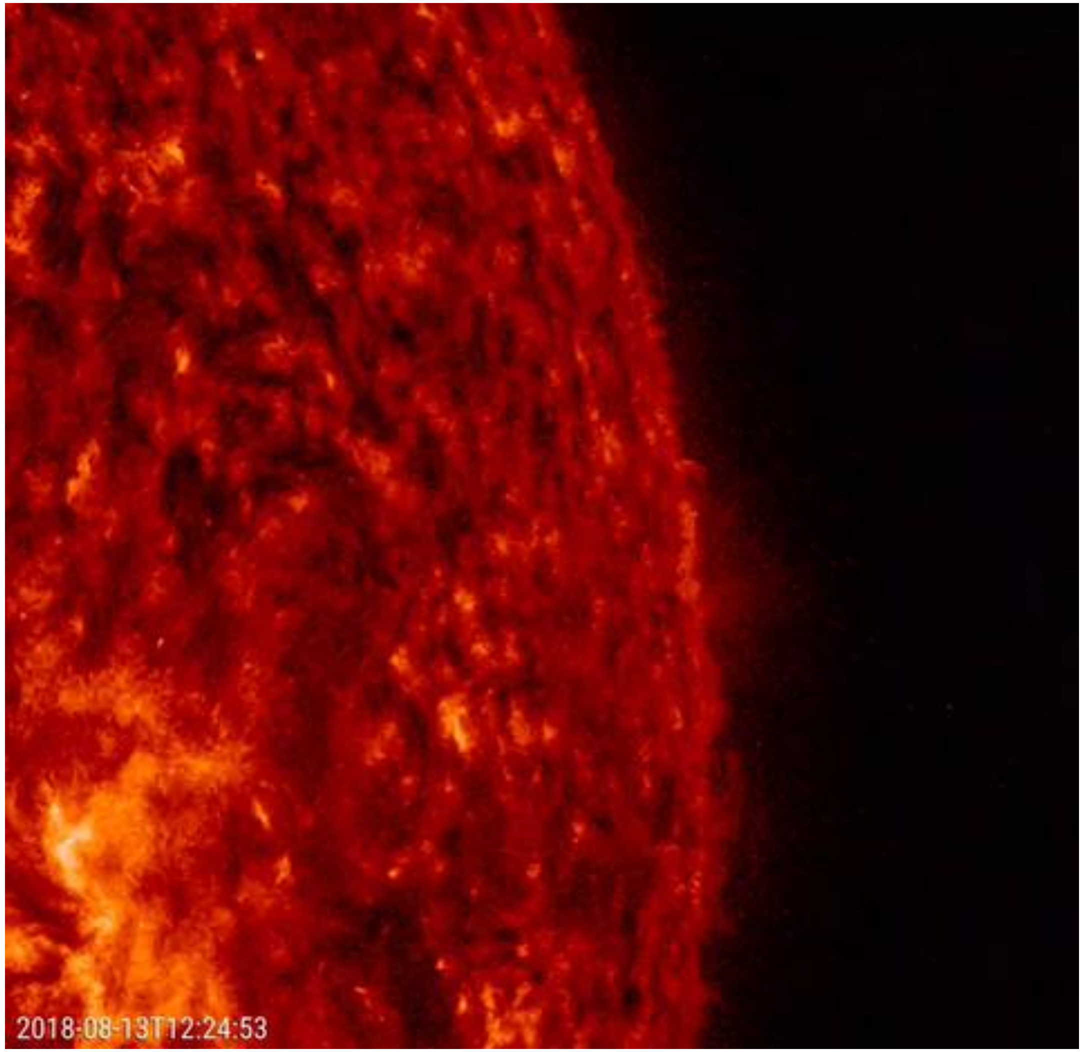
Effect of solar x-rays on the atmosphere: HF radio disruption.

Scale	Description	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
R 5	Extreme	**HF Radio:** Complete HF (high frequency) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. **Navigation:** Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 (2×10^{-3})	Less than 1 per cycle
R 4	Severe	**HF Radio:** HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. **Navigation:** Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	**HF Radio:** Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. **Navigation:** Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	**HF Radio:** Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. **Navigation:** Degradation of low-frequency navigation signals for tens of minutes.	M5 (5×10^{-5})	350 per cycle (300 days per cycle)
R 1	Minor	**HF Radio:** Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. **Navigation:** Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

Magnetic field can become extremely twisted.

When the magnetic field tension is released, it can carry material out in to space.

This is called a Coronal Mass Ejection.



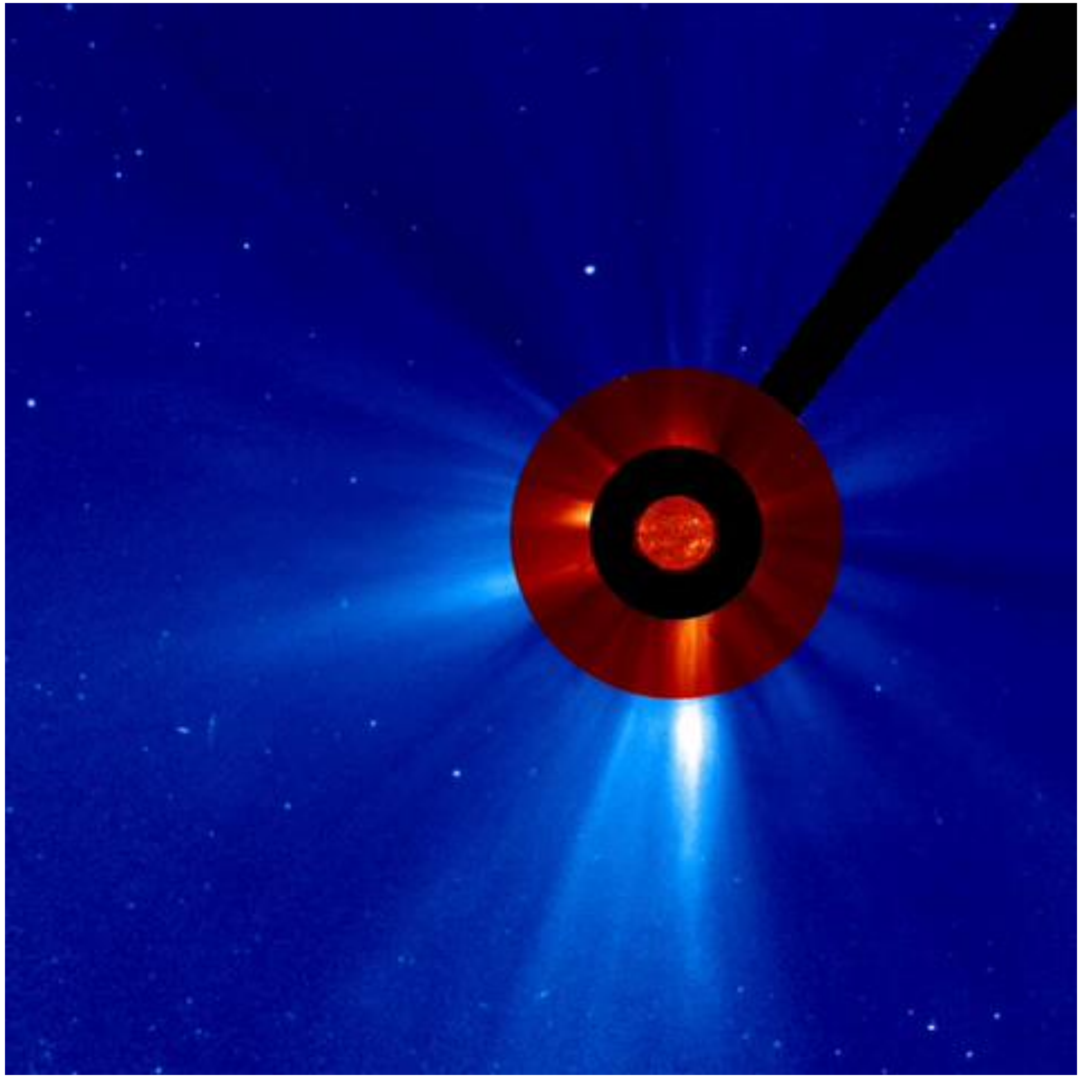
What does a CME look like from far away?

Coronagraph blocks out light from the Sun, allowing us to see faint gas expelled from the Sun.

An image of the Sun has been superimposed on the occulted region.

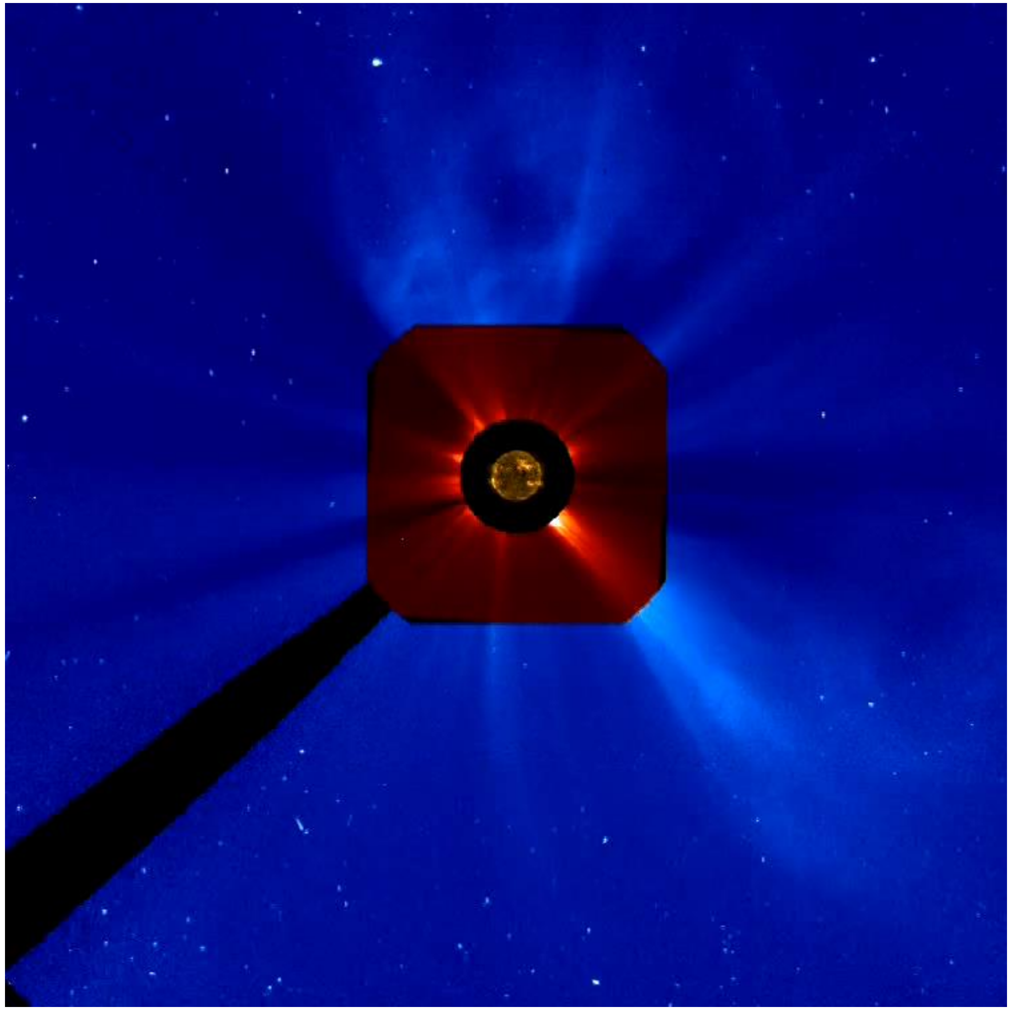
Eruptions do not always move with the same apparent speed.

Is the eruption at the top moving slower, or is it coming straight at us?



How do we know if the ejected material will hit the Earth?

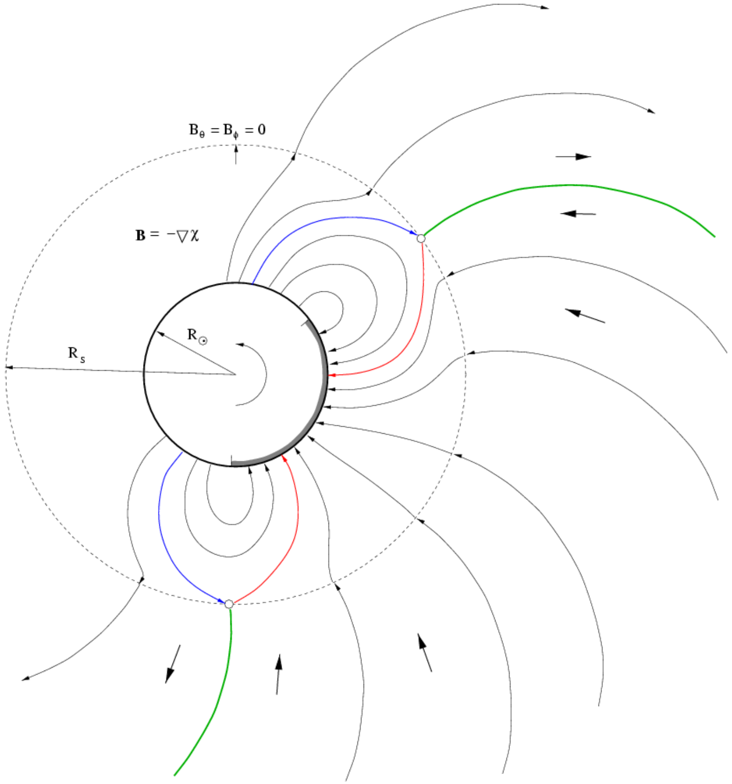
We shall see….

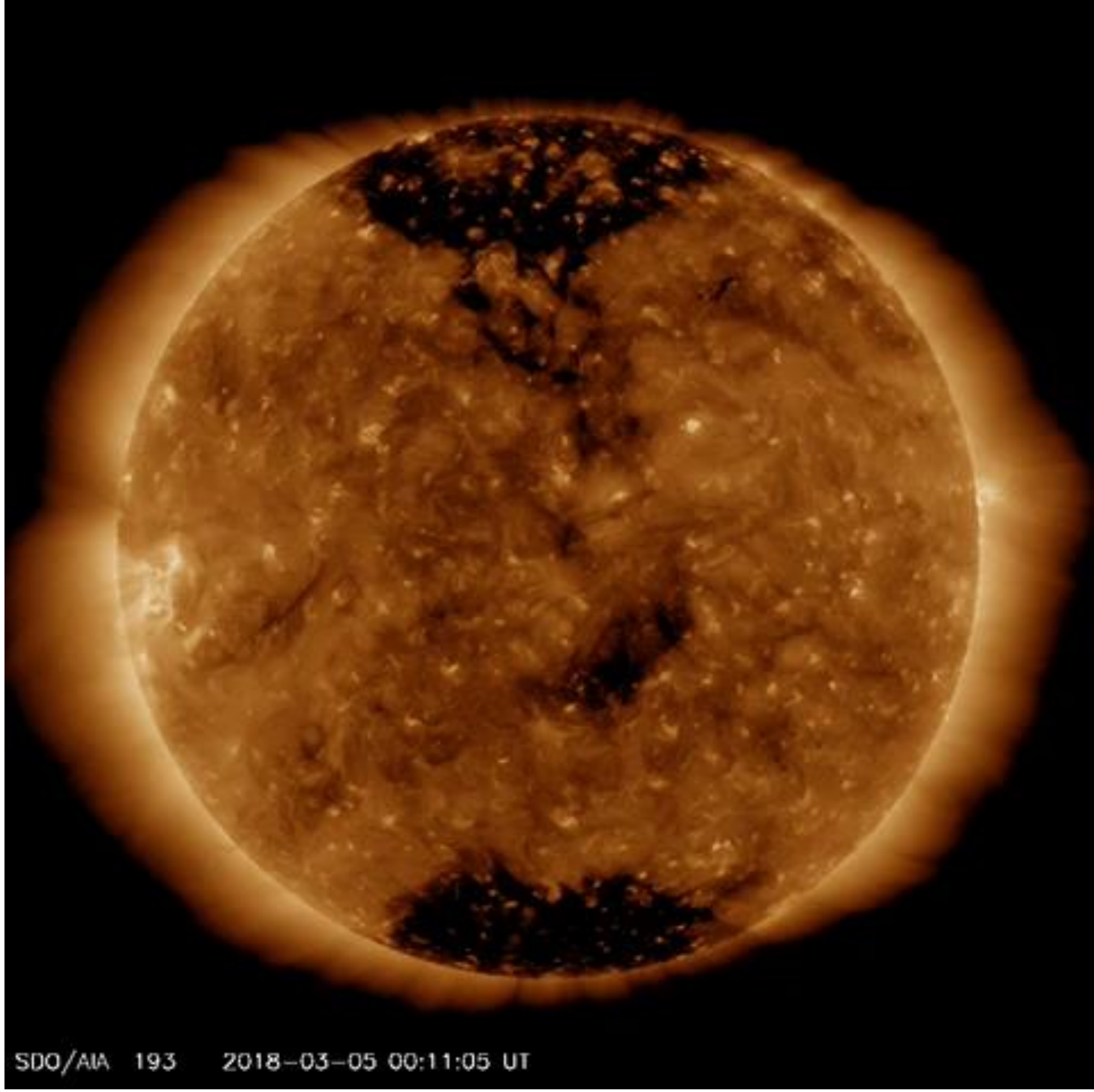


Magnetic structures connect one area on the Sun to another.

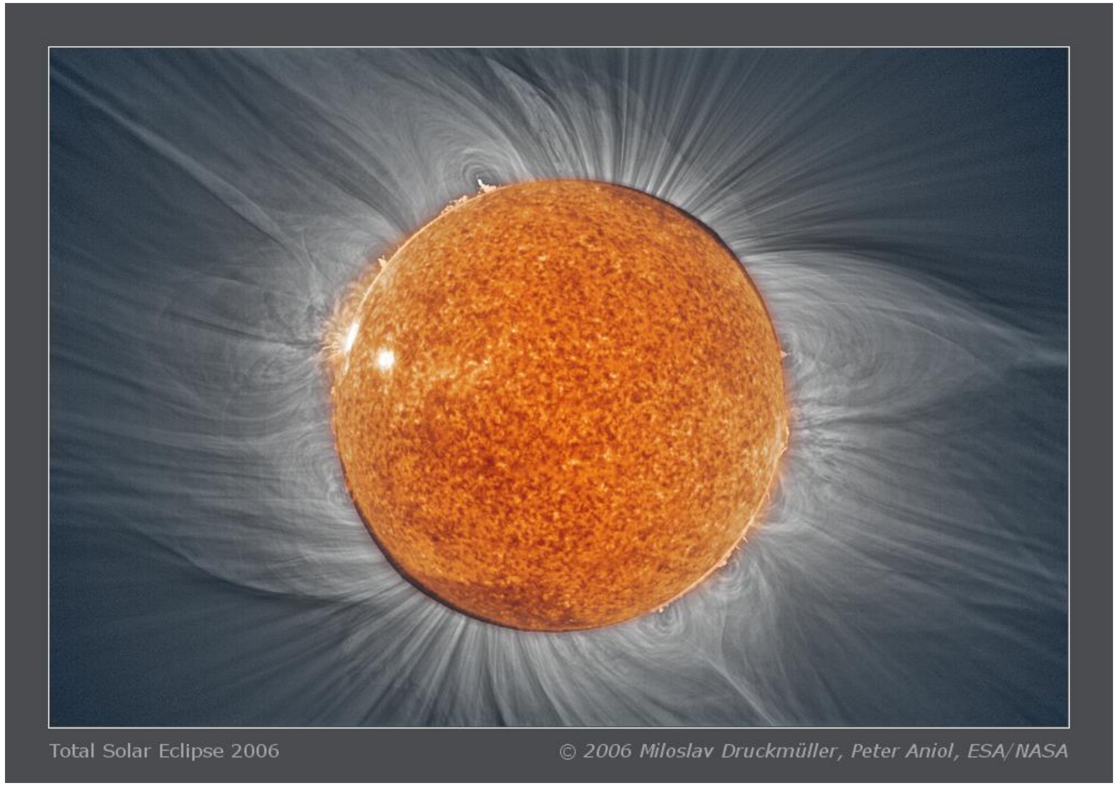
Spaces in between are known as Coronal Holes.

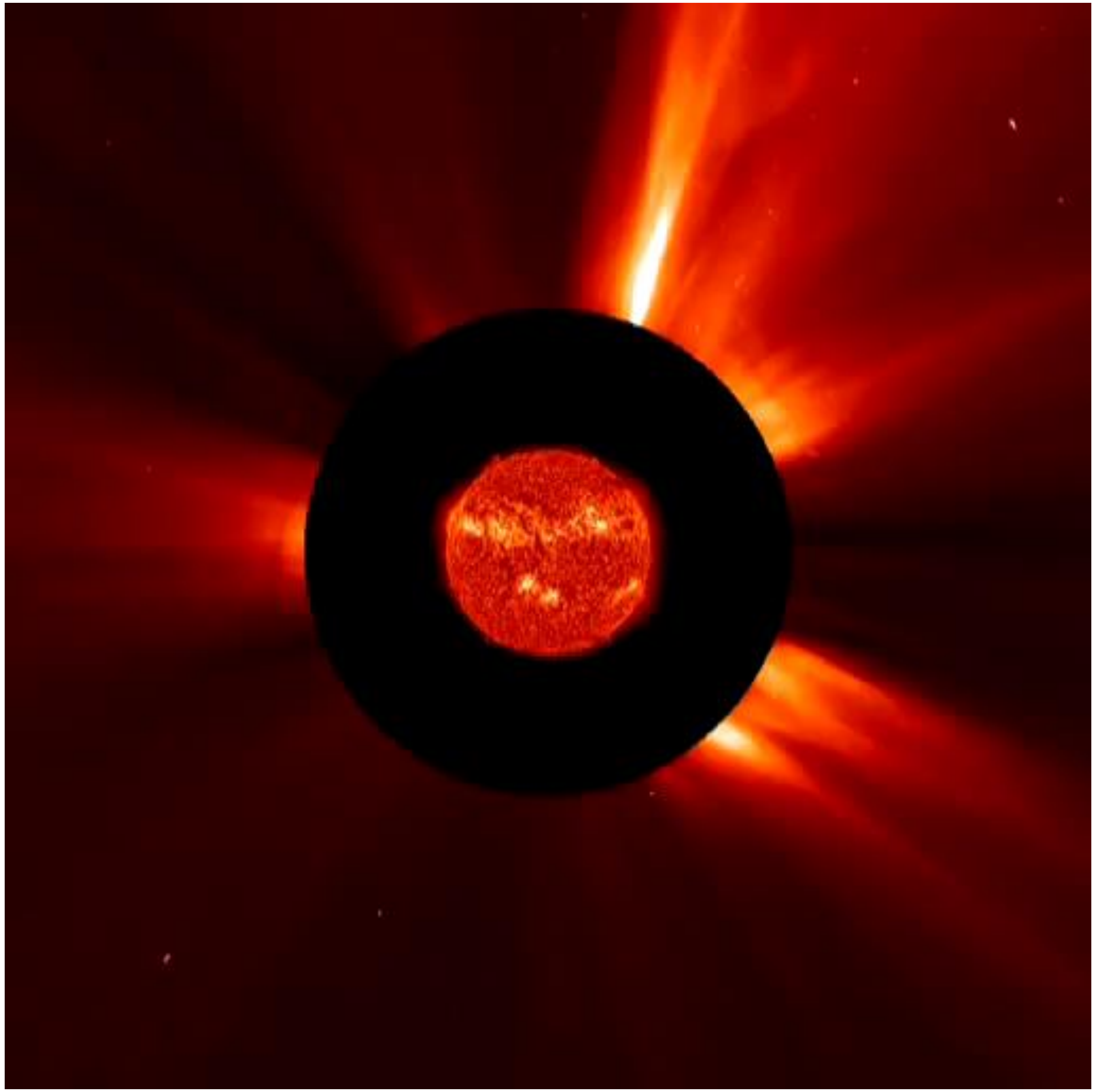
A continual stream of plasma flows out of these holes, known as the solar wind.

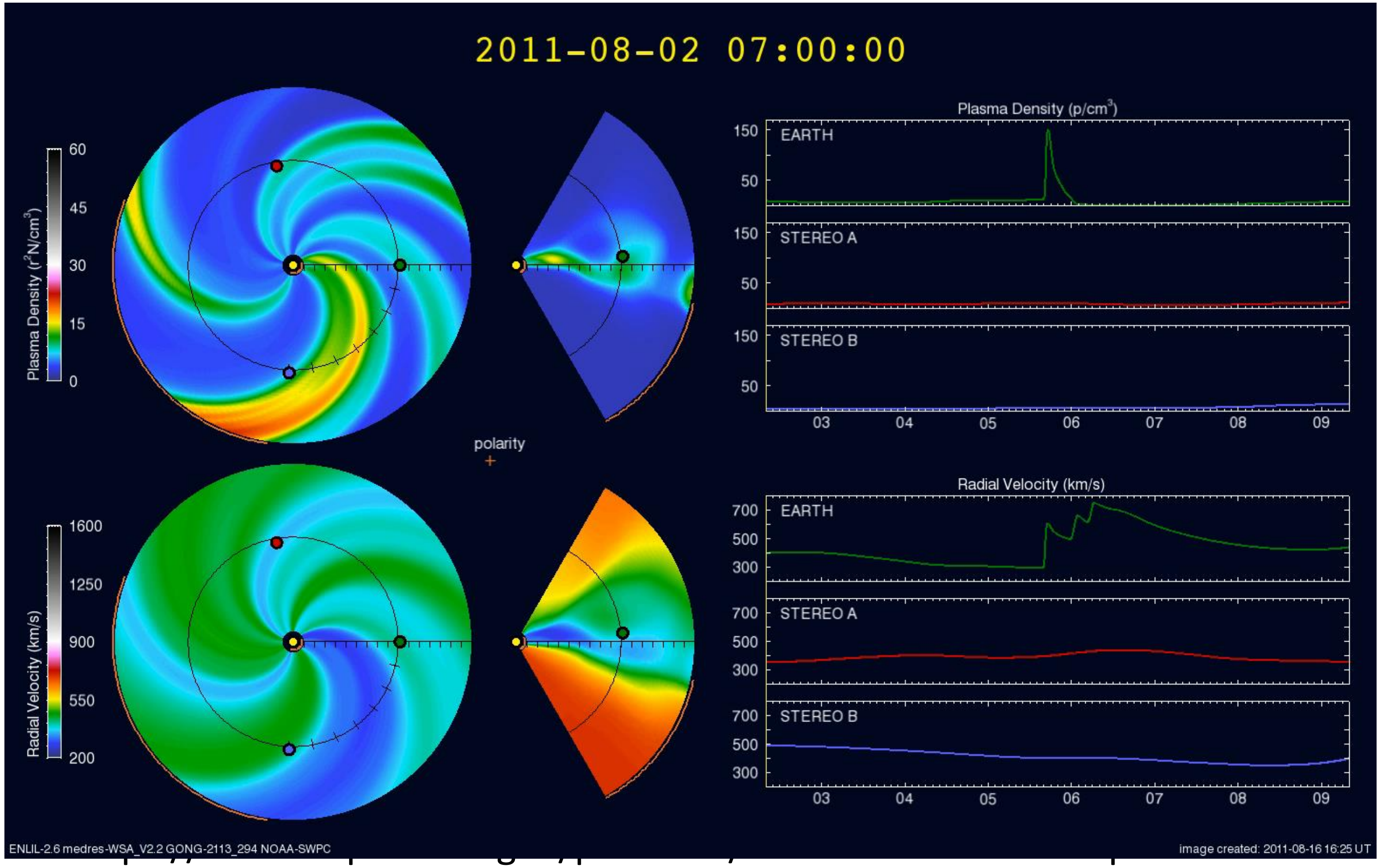




CMEs burst out on top of the steady solar wind.







Since the Sun is rotating, the solar wind looks bent in a spiral pattern.

Slow solar wind 400 km/s

Fast solar wind 800 km/s

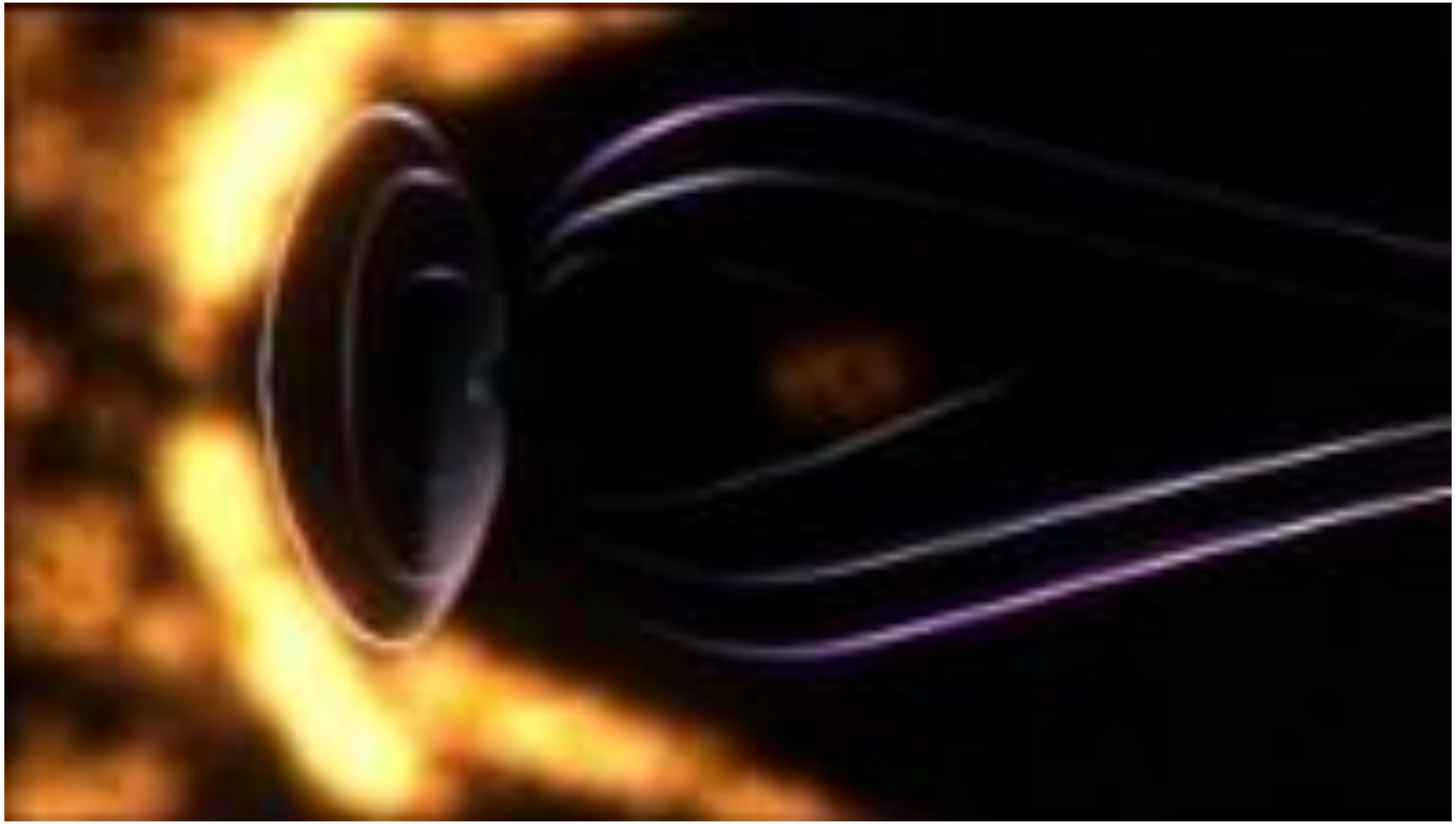
What happens when a CME hits the Earth?

Does it hit directly?

What is the magnetic field orientation of the CME?

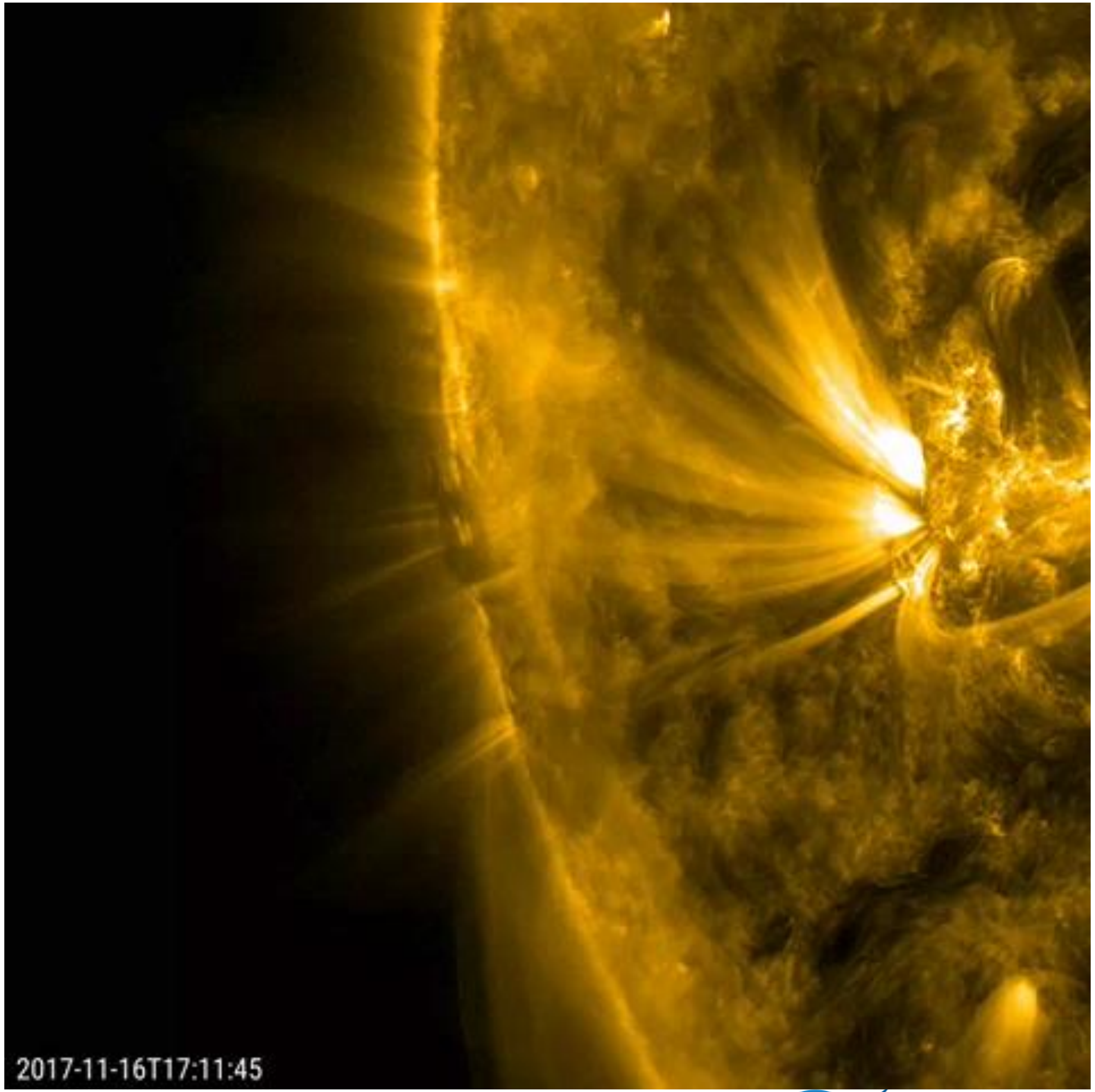
What is the density of the CME?

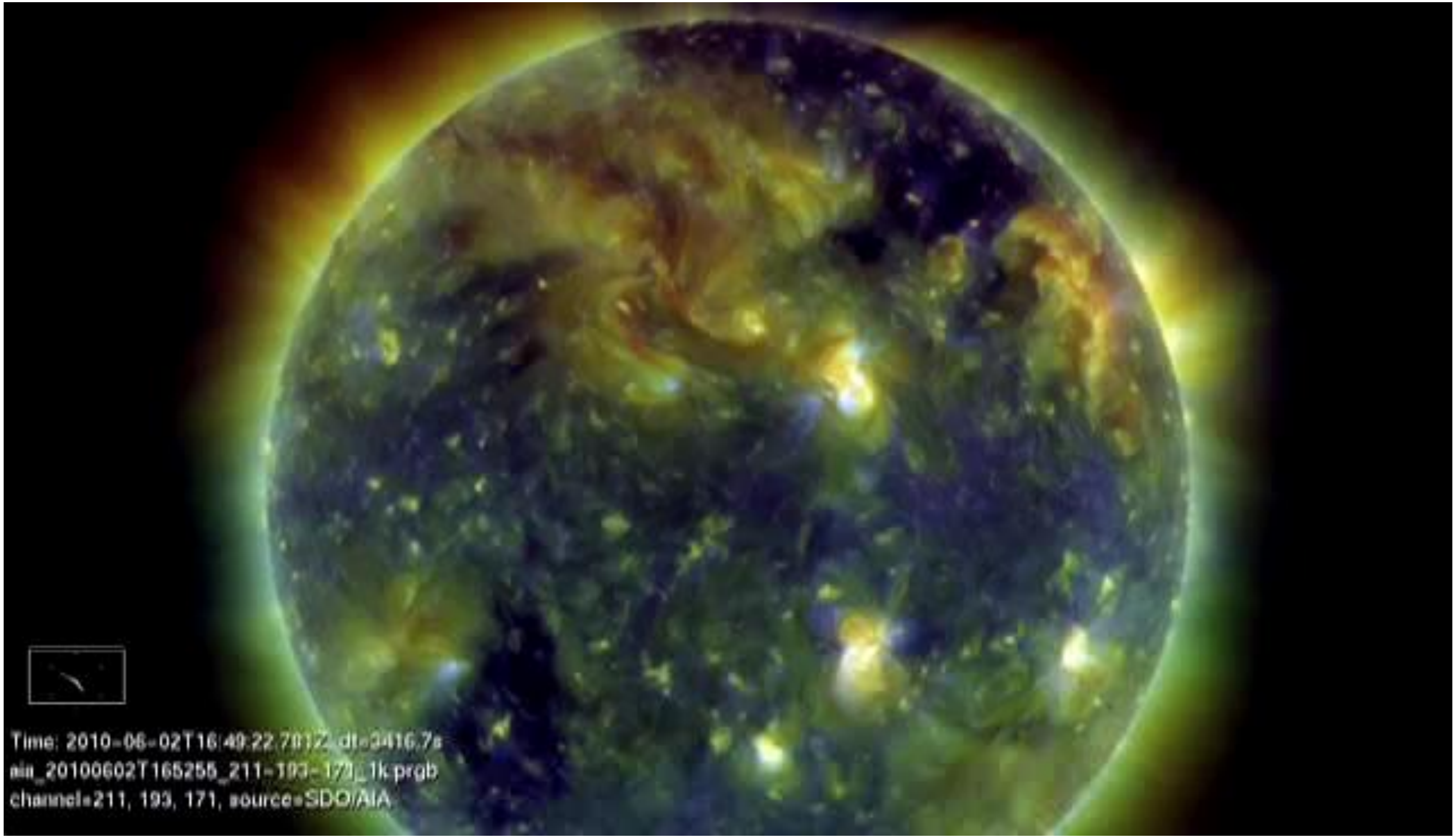
Why are there so many questions?



What is coming around the corner?

Only Space Weather Forecasters know!

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Thank you

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